ASAP Advanced Surfaces And Processes, Inc.

Results of materials testing for ElectroSpark Deposition

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Advanced Surfaces and Processes, Inc.

HCAT Program Review Meeting
Hilton San Diego Resort
1775 East Mission Bay Drive
San Diego, CA 92109

Report Documentation Page

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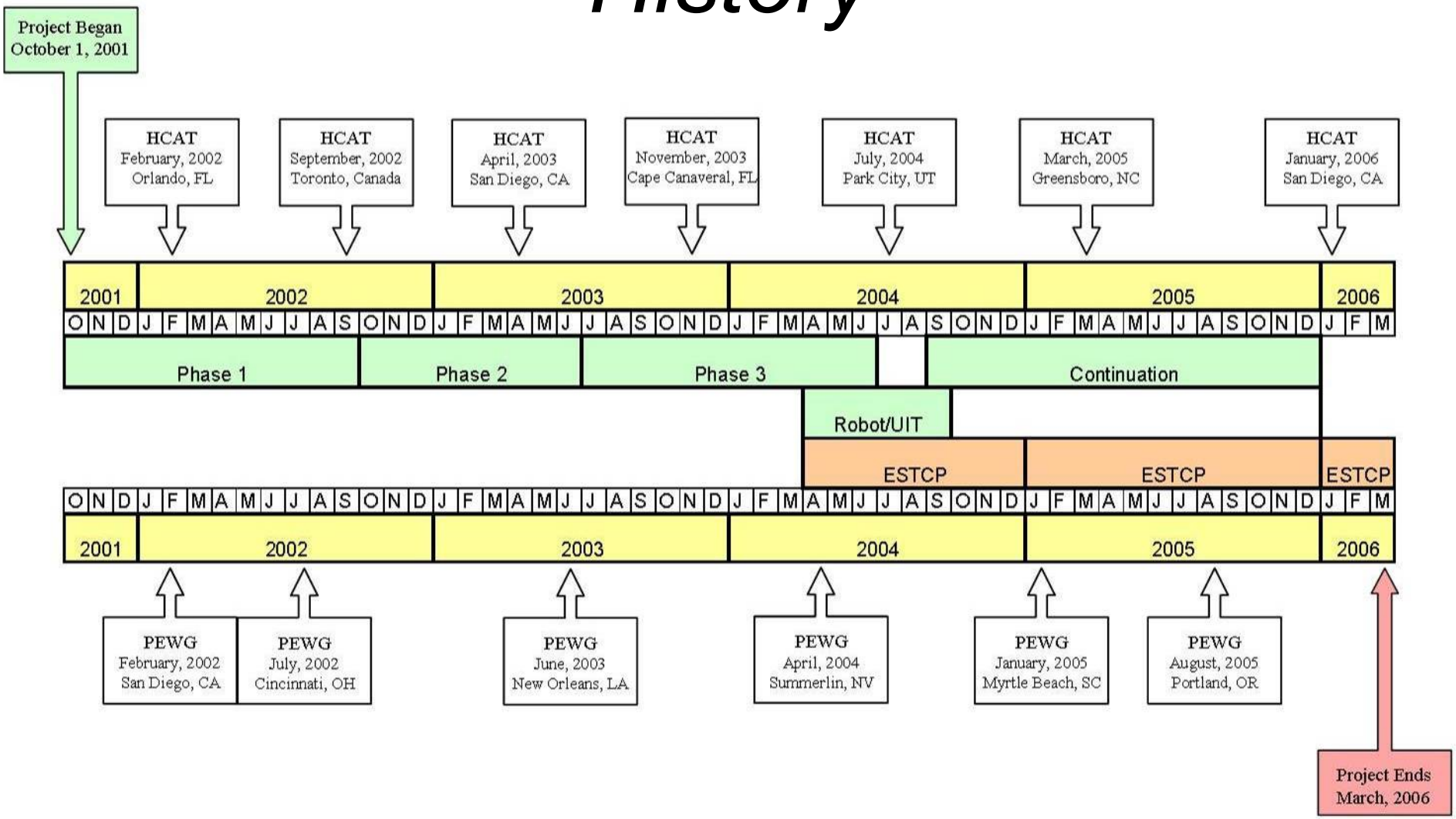
History


Project Began October 1, 2001
HCAT February, 2002 Orlando, FL
HCAT September, 2002 Toronto, Canada
HCAT April, 2003 San Diego, CA
HCAT November, 2003 Cape Canaveral, FL
HCAT July, 2004 Park City, UT
HCAT March, 2005 Greensboro, NC
HCAT January, 2006 San Diego, CA
2001
2002
2003
2004
2005
2006
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M
Phase 1
Phase 2
Phase 3
Continuation
Robot/UIT
ESTCP
ESTCP
ESTCP
PEWG February, 2002 San Diego, CA
PEWG July, 2002 Cincinnati, OH
PEWG June, 2003 New Orleans, LA
PEWG April, 2004 Summerlin, NV
PEWG January, 2005 Myrtle Beach, SC
PEWG August, 2005 Portland, OR
Project Ends March, 2006

Project Objective

The goals of this project are to *demonstrate and validate* ElectroSpark Deposition (ESD) as technically feasible and commercially viable for a production-scale process, and to perform the tests necessary to transition ESD for use on gas turbine engine components.

Participants

- ESTCP/HCAT
- PEWG
- Portland State University
- Edison Welding Institute
- Rowan Technology Group
- Pacific Northwest National Lab
- Air Force Research Lab
- Metcut
- Hamilton Sundstrand
- General Electric Aircraft Engines
- Pratt & Whitney
- Tinker AFB

Milestones

- *Materials*
- *Optimization of ESD*
- *ESD/Robotics/UIT*
- *Joint Test Protocol*
- *ESD on Chrome Plate*
- *Components*

HCAT Member WorkSpace →ESD→Test Plans→Demonstration Plan

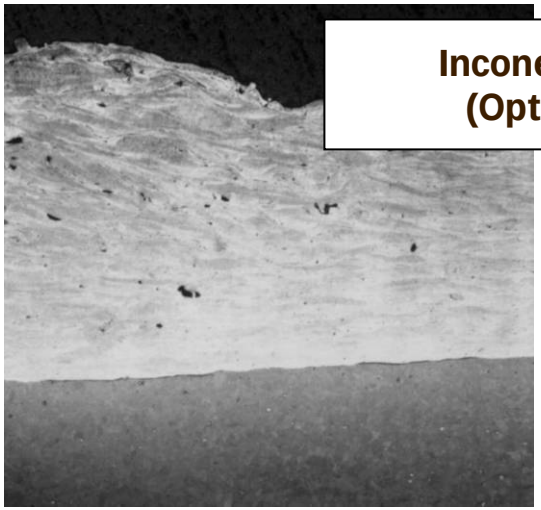
What is ESD?

The ESD process is a capacitive discharge micro-arc process using a consumable electrode.

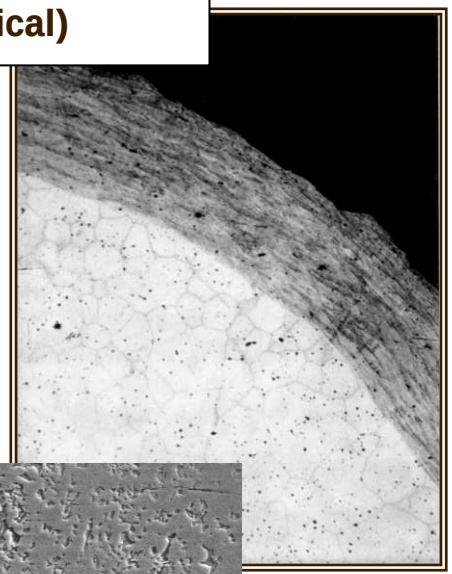
The electrode and substrate materials are melted, rapidly solidify, and build-up occurs incrementally.

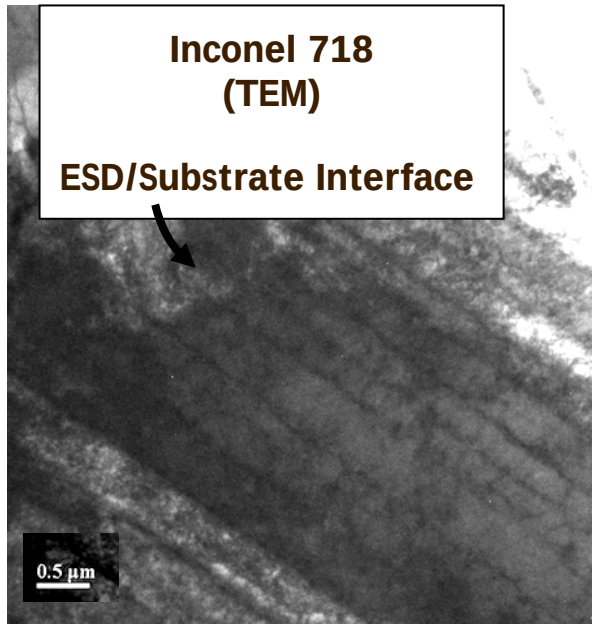
- Metallurgical bond
- Low heat input
- Rapid solidification
- No pre-ESD preparation
- No post-ESD processing
- Environmentally benign
- Portable
- Applicable for NLOS

Materials



Inconel 718
(Optical)

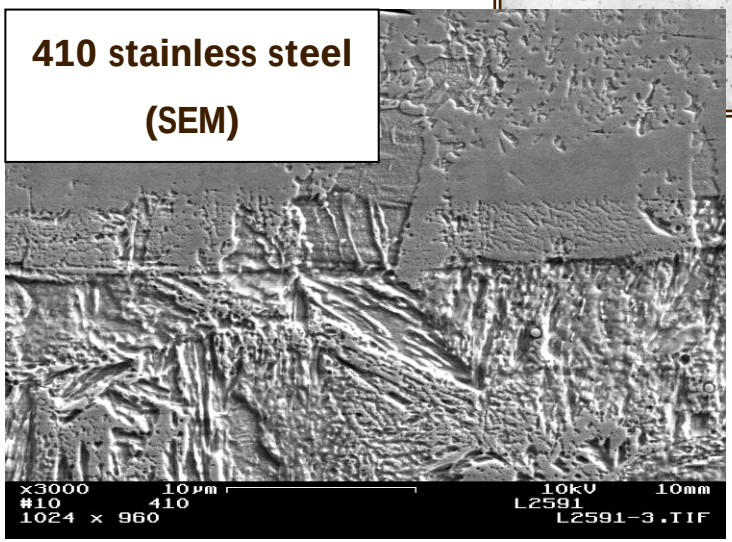




Inconel 718
(TEM)

ESD/Substrate Interface

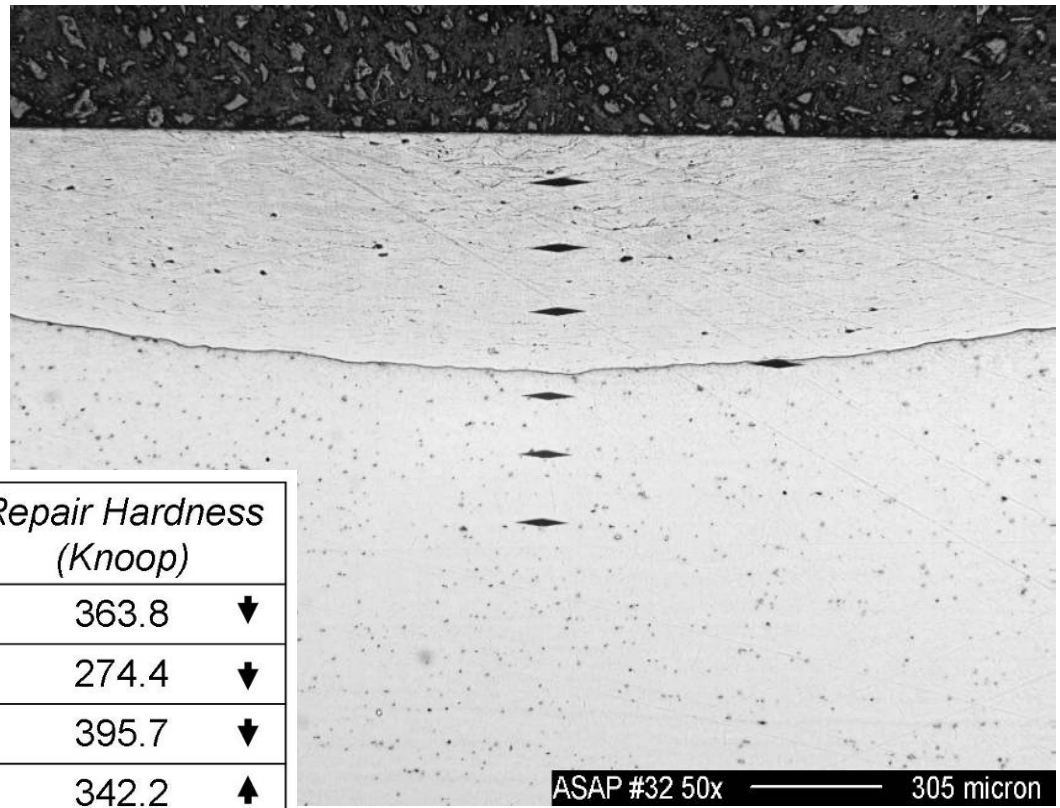
410 stainless steel
(SEM)



- Hastelloy X
- 17-4 PH
- Haynes 188
- IN 625
- **IN 718**
- 410 SS
- Ti-6Al-4V

Discontinuities and μ–hardness

Material	Discontinuities Average Volume (%)
17-4 PH	1.88
410 SS	2.42
Hastelloy X	2.19
Haynes 188	2.26
Inconel 625	1.35
Inconel 718	1.41
Ti-6Al-4V	1.62



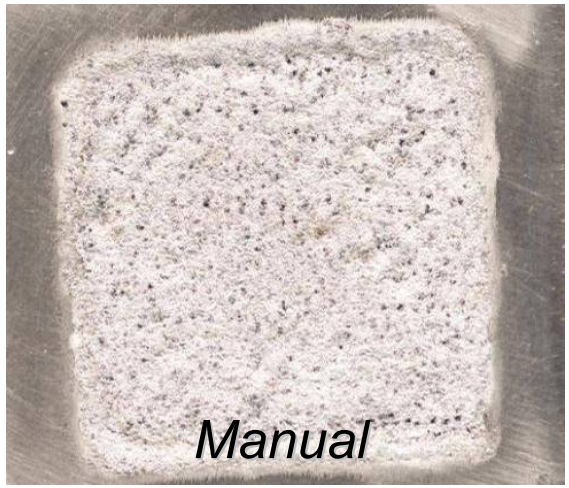
Material	Substrate Hardness (Knoop)	Repair Hardness (Knoop)
Inconel 718	526	363.8 ▼
17-4 PH	480	274.4 ▼
410 SS	509	395.7 ▼
Hastelloy X	246	342.2 ▲
Haynes 188	292	385.6 ▲
Inconel 625	267	363.4 ▲
Ti-6Al-4V	330	383.7 ▲

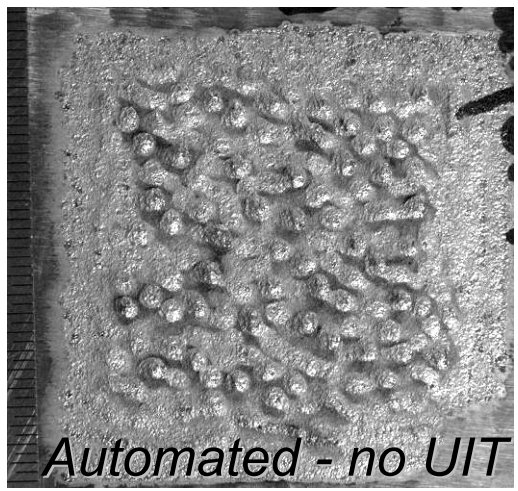
Optimization

- *Materials of Interest*
  - *IN718 on IN 718*
  - *410 SS on 410 SS*
  - *Ti-6Al-4V on Ti-6Al-4V*
  - *IN 625 on chrome plated IN 718*
- *DOE Optimization*
  - *Deposition Rate*
  - *Microhardness*
  - *Porosity*
- *Parameters Selected for Execution of Joint Test Protocol*
- *Added UIT*

ESD, Robotics and UIT

Objective: Demonstrate improvement in quality and production rates of an ESD repair on IN718 through automation and ultrasonic impact treatment (UIT).



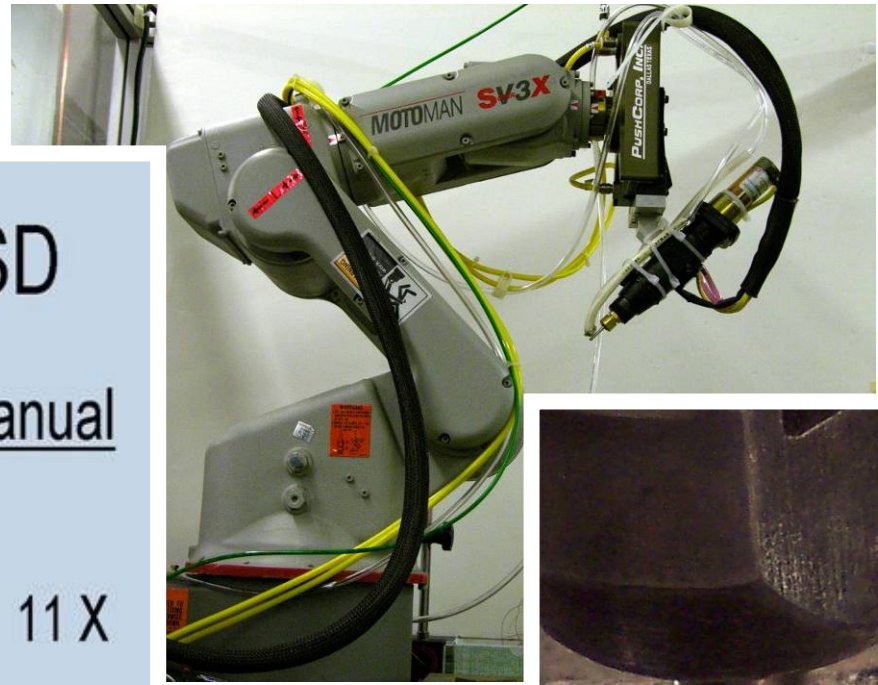


ESD, Robotics and UIT

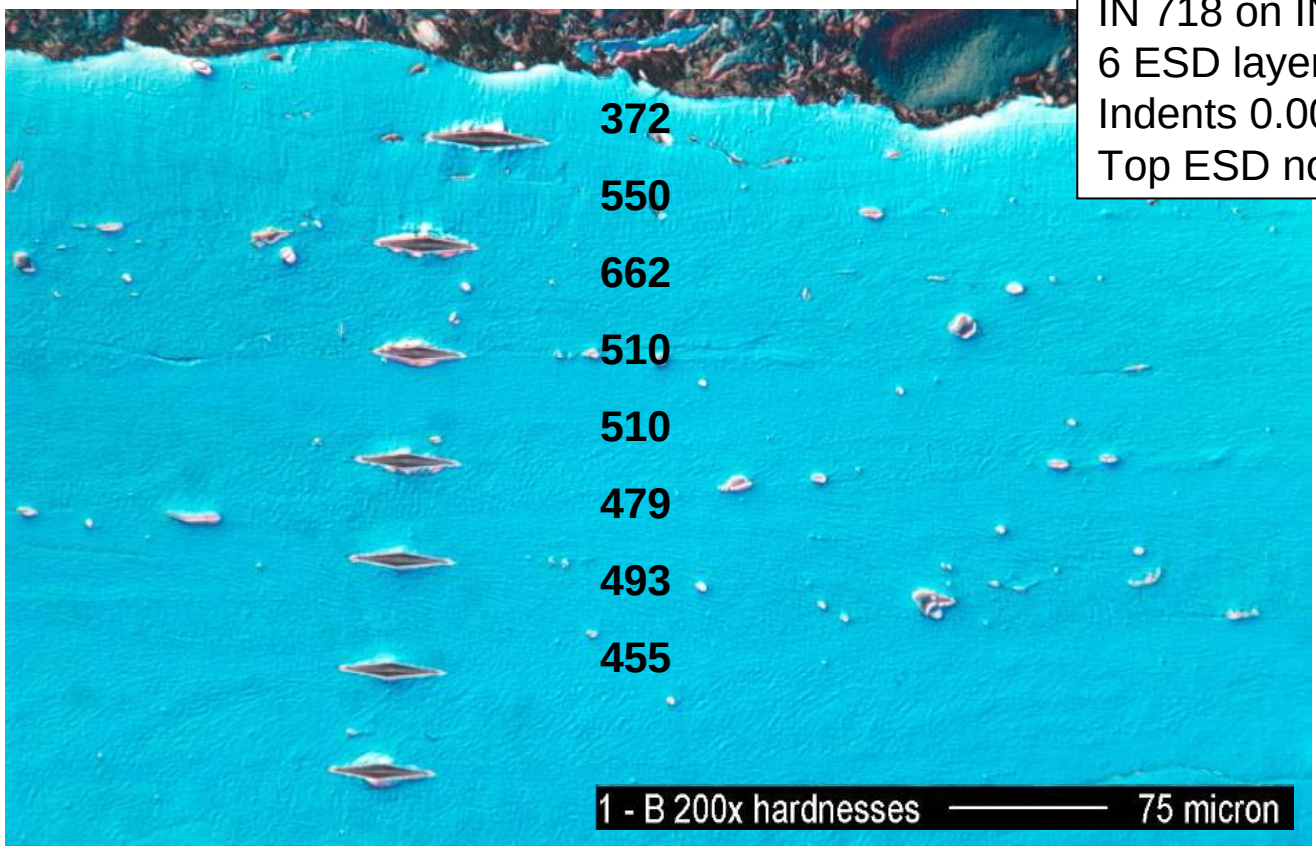
Improvement in ESD

Automated with UIT vs. Manual

Production Deposition Rates	↑	11 X
Discontinuities	↓	0.8 X
Hardness	↑	1.3 X

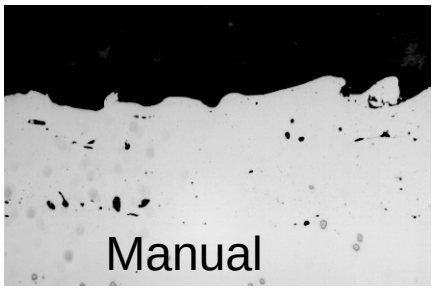


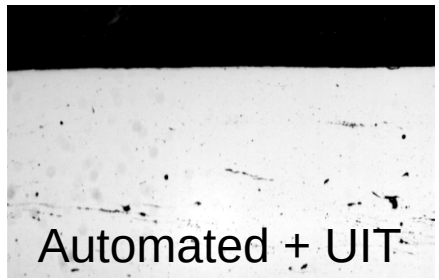
μ-hardness with UIT

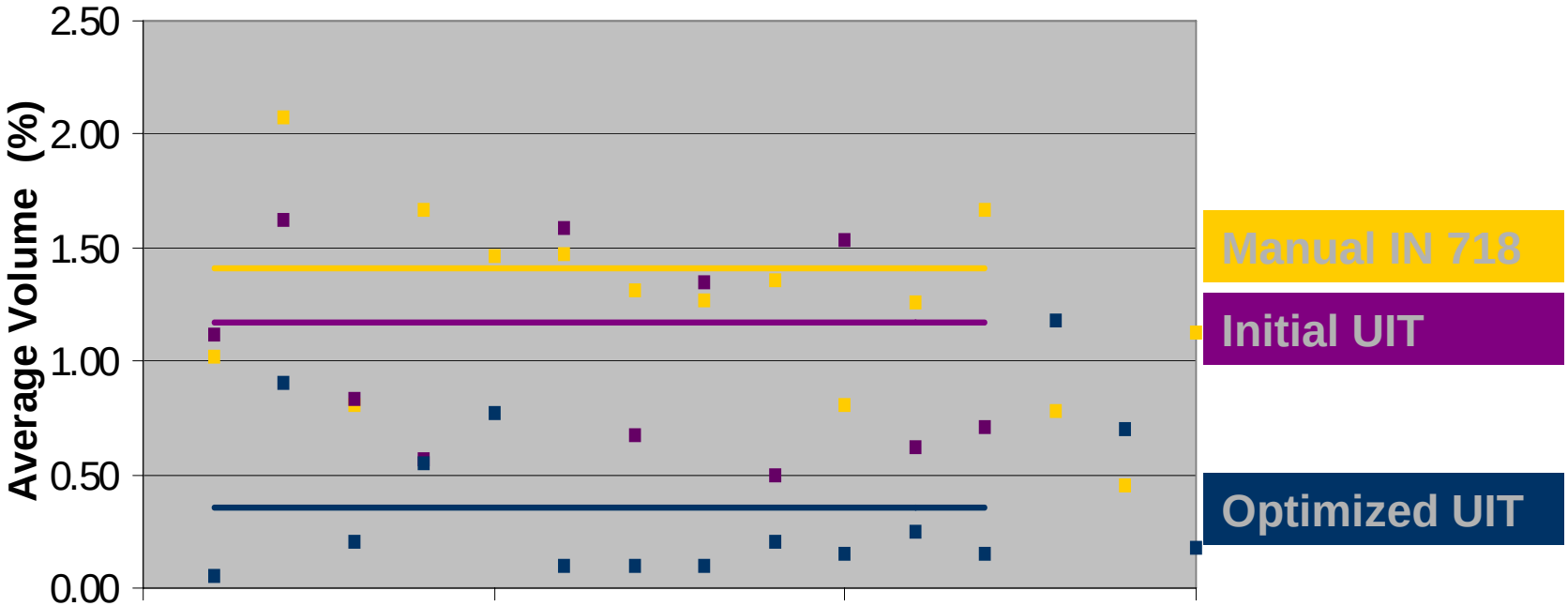


IN 718 on IN 718
6 ESD layers
Indents 0.005” apart
Top ESD no UIT

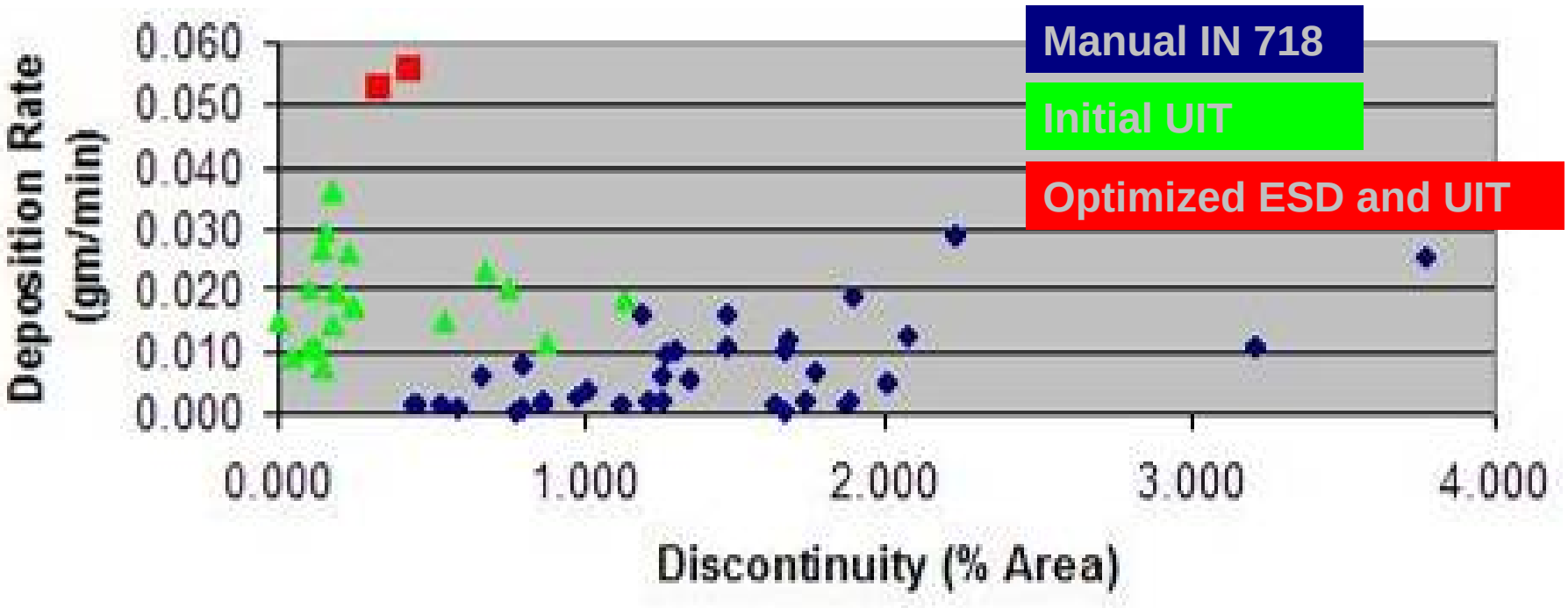
Discontinuities with UIT







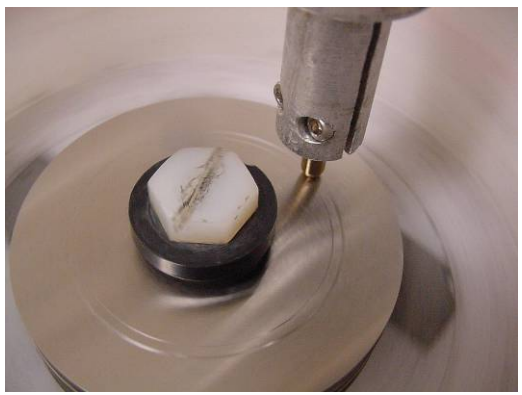
Deposition Rate with UIT



Joint Test Protocol

- *Pin on Disk Wear*
- *Fatigue*
- *Residual Stress*
- *Corrosion*
- *Adhesion Bond*
- *Tensile*
- *Hamilton Sundstrand Wear*

Pin on Disk Wear

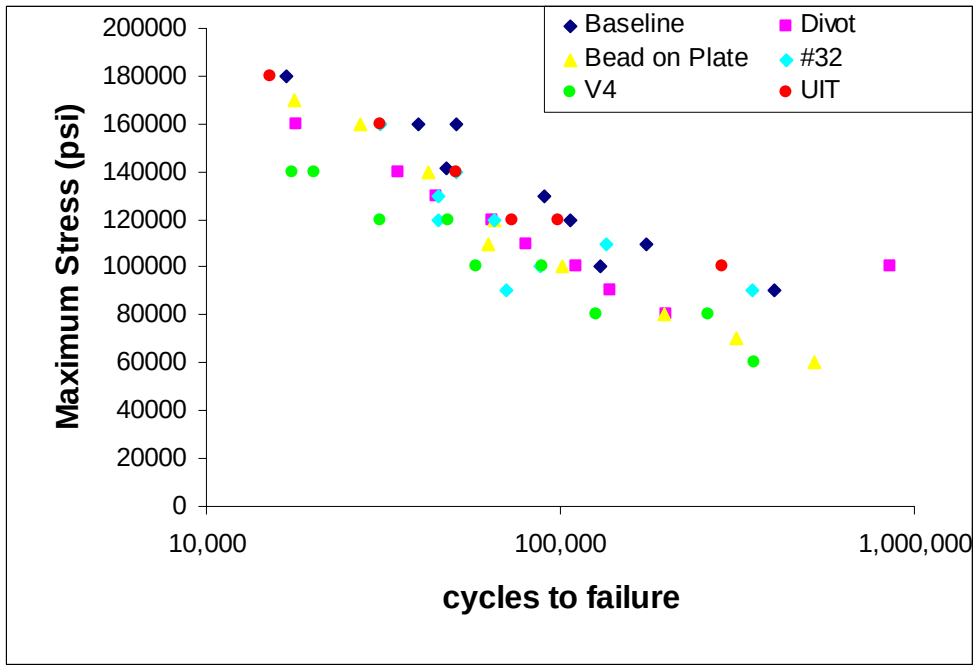


Specimen	Maximum Groove Depth	
	Base Metal	ESD
2-1 (V4)	114	134
2-2 (V4)	92	153
2-4 (#32)	128	123
2-3 (#32) long test	218	194

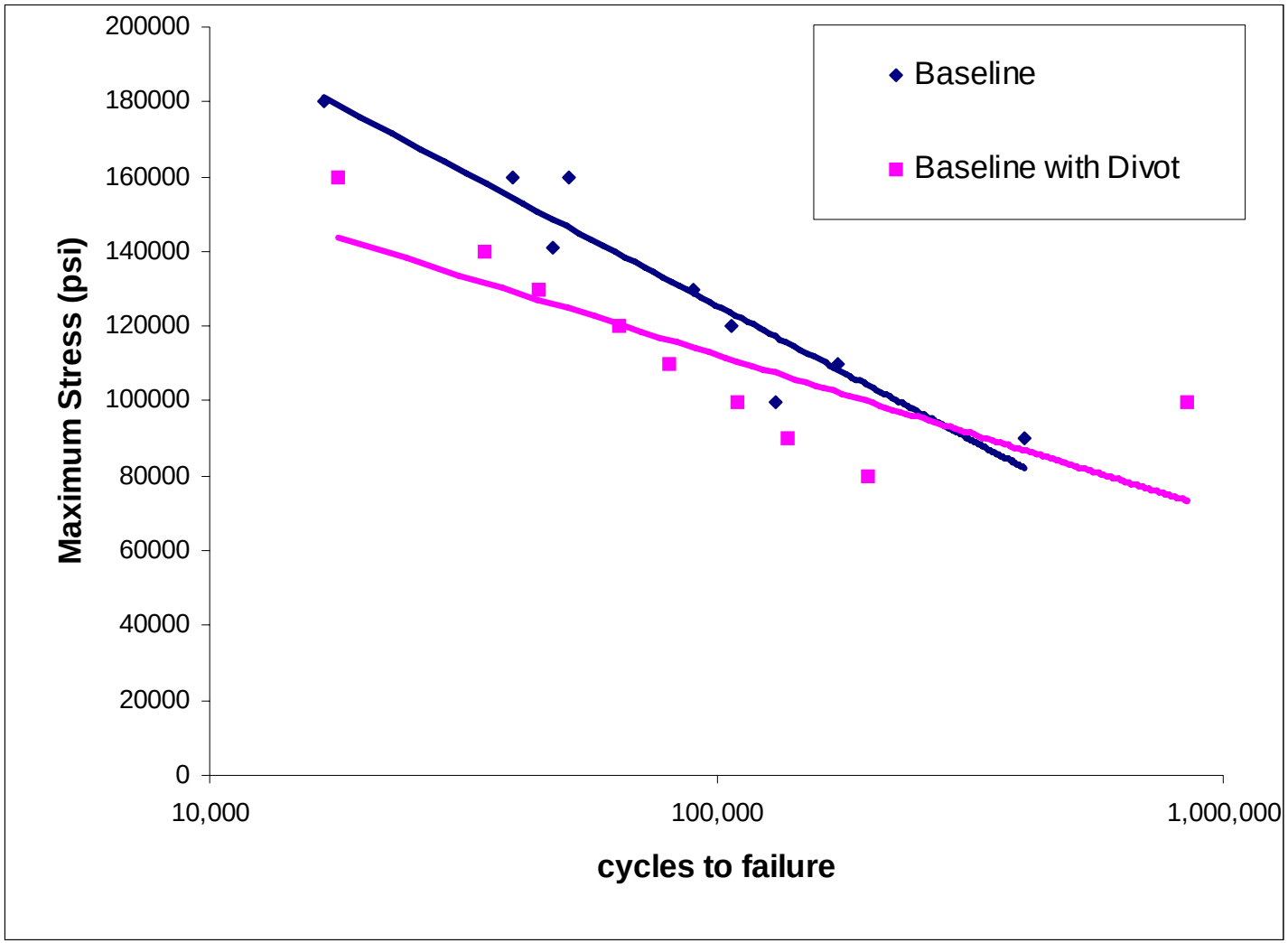
Fatigue


INITRON
14.12.2004

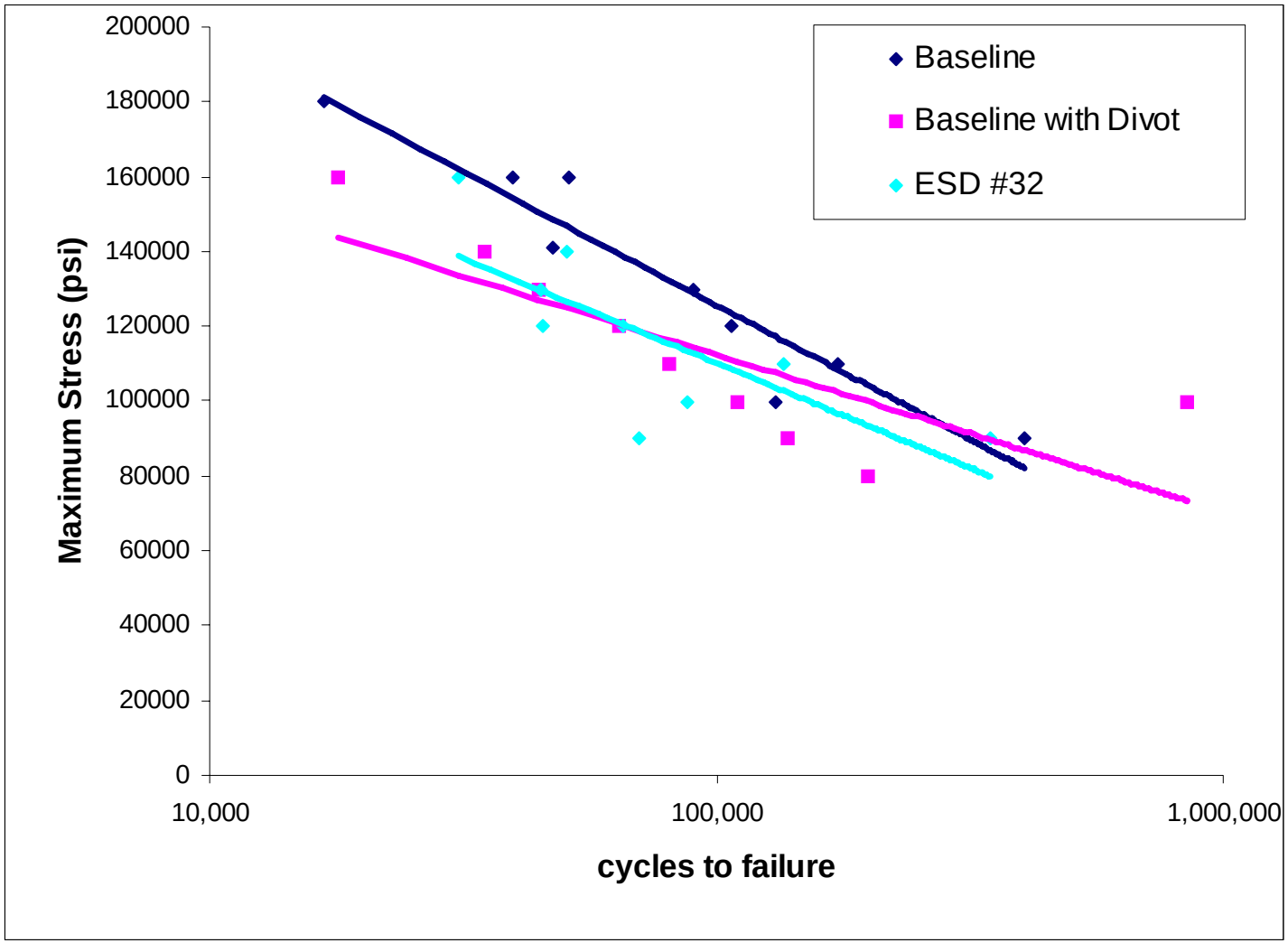

FAT-13


Baseline
Divot
Bead on Plate
#32
V4
UIT
Maximum Stress (psi)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
10,000
100,000
1,000,000
cycles to failure

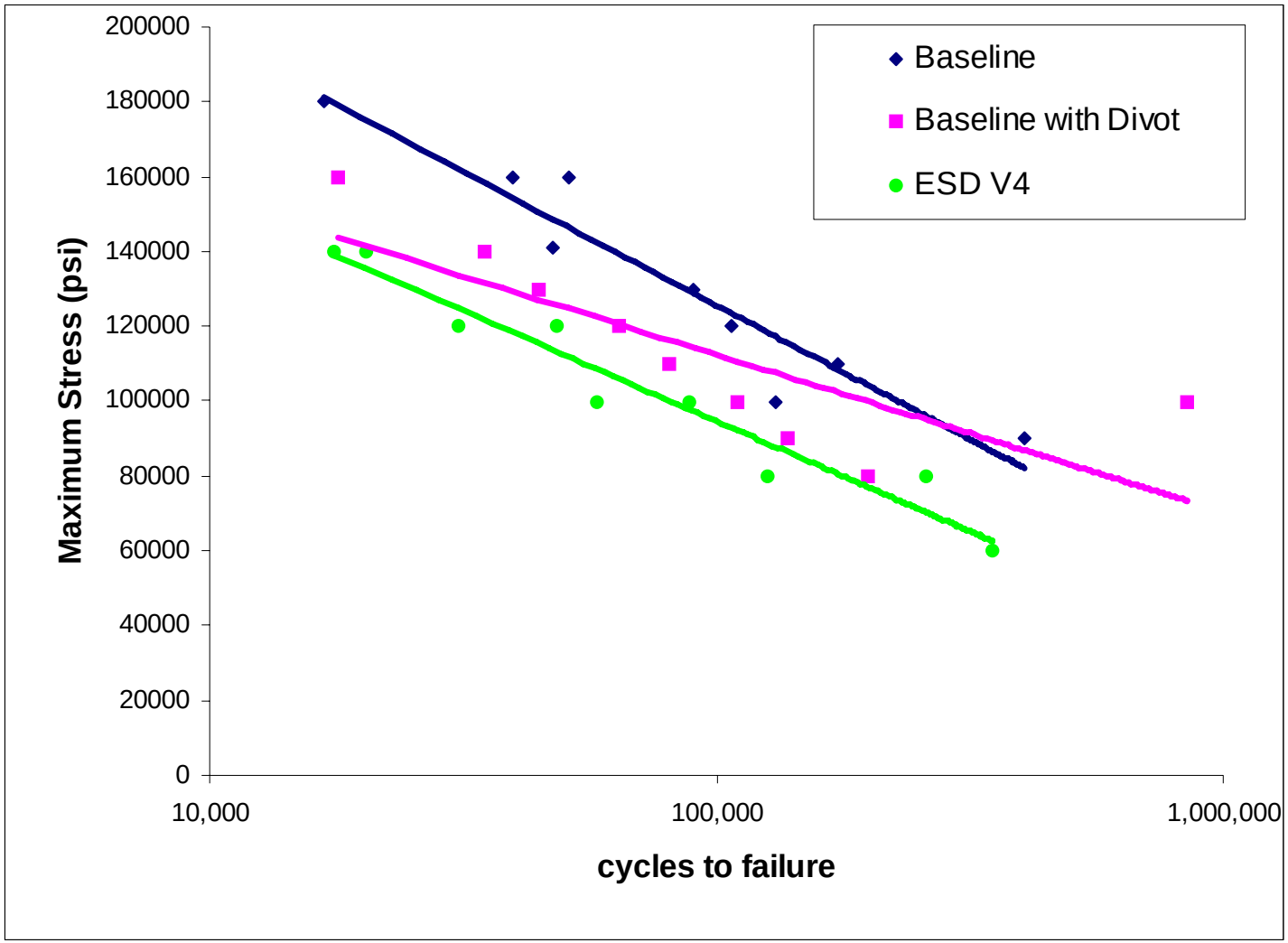
Fatigue


200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Maximum Stress (psi)
10,000
100,000
1,000,000
cycles to failure
Baseline
Baseline with Divot

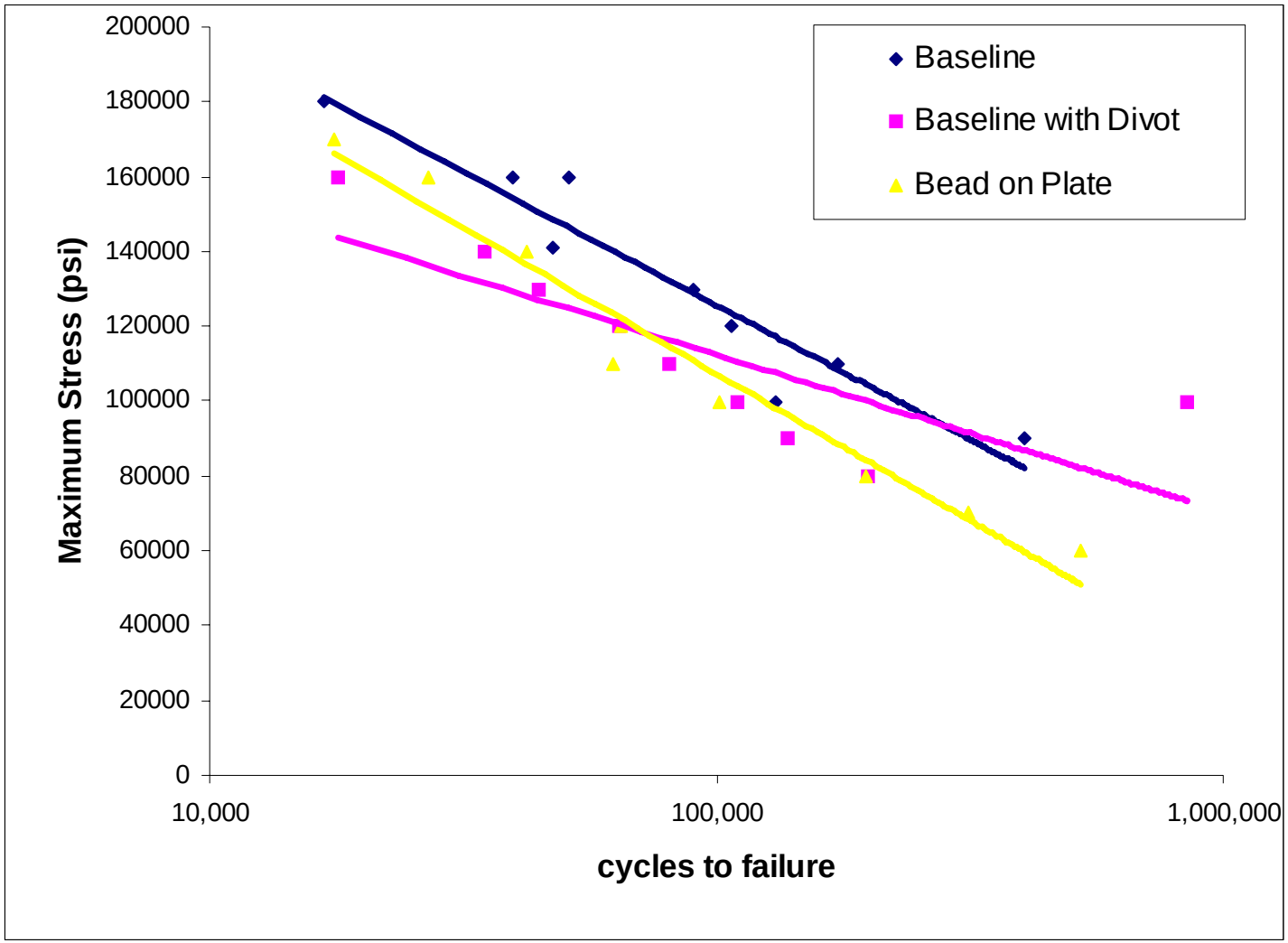
Fatigue


200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Maximum Stress (psi)
10,000
100,000
1,000,000
cycles to failure
Baseline
Baseline with Divot
ESD #32

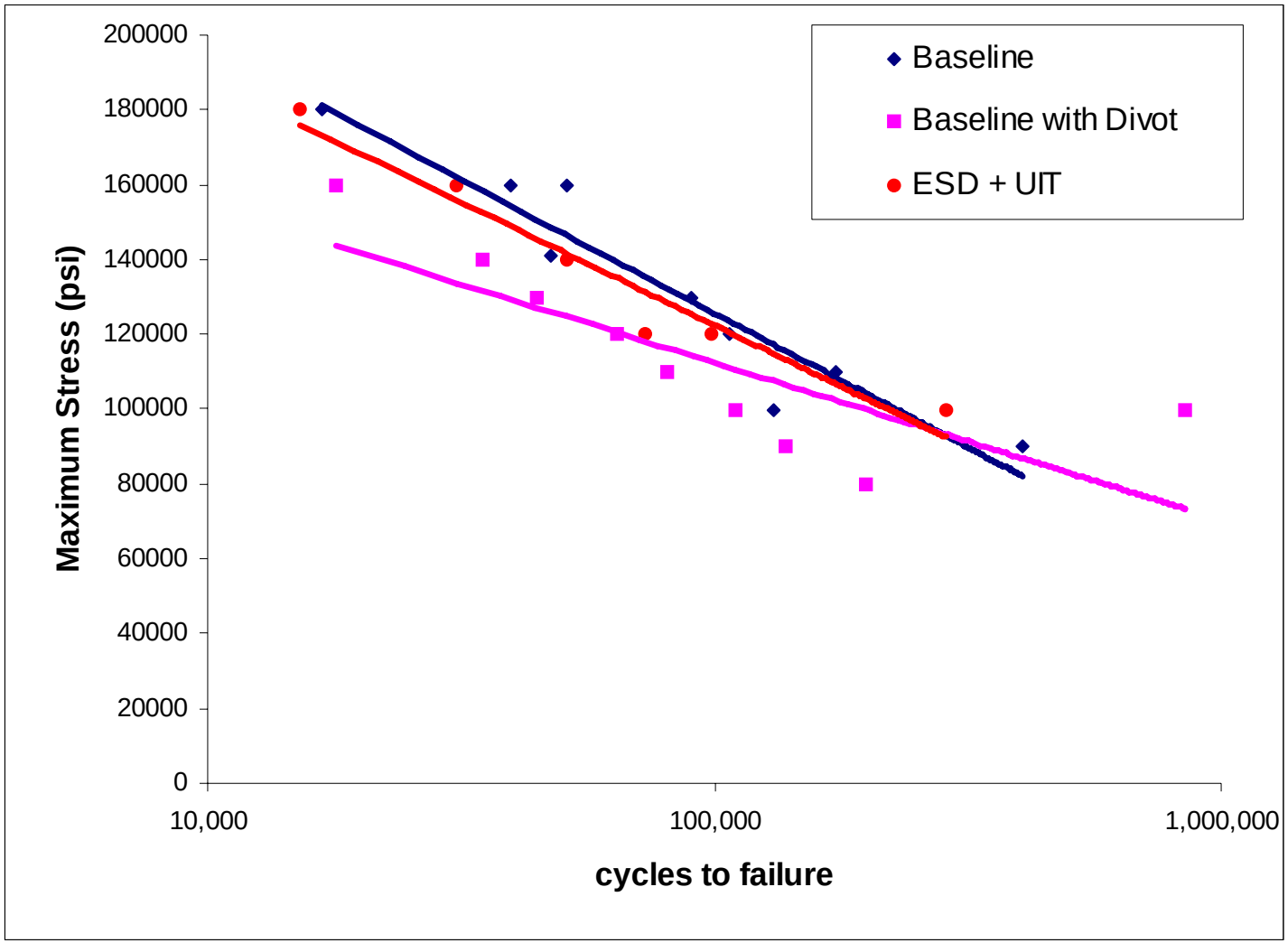
Fatigue


200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Maximum Stress (psi)
10,000
100,000
1,000,000
cycles to failure
Baseline
Baseline with Divot
ESD V4

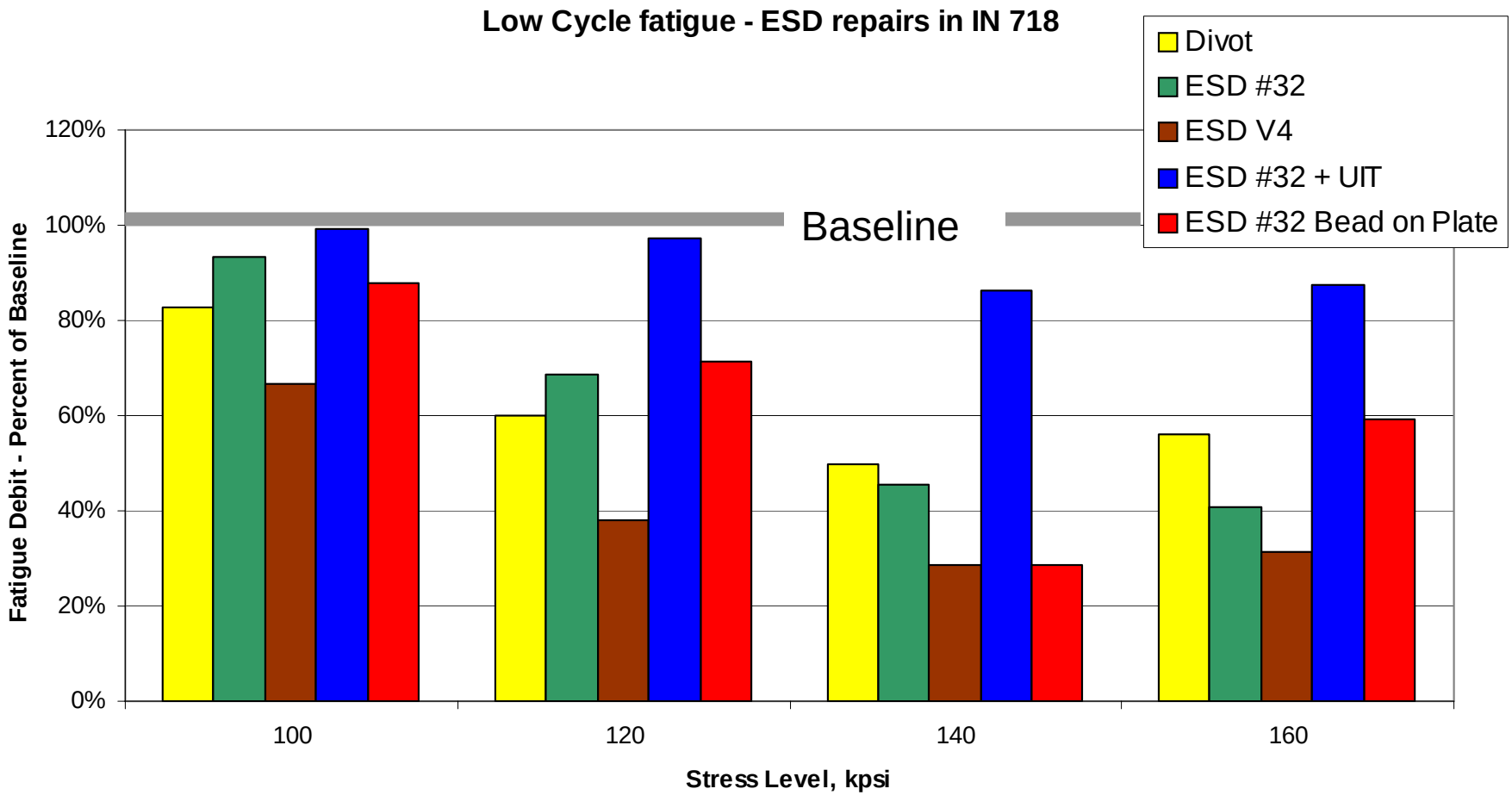
Fatigue


200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Maximum Stress (psi)
10,000
100,000
1,000,000
cycles to failure
Baseline
Baseline with Divot
Bead on Plate

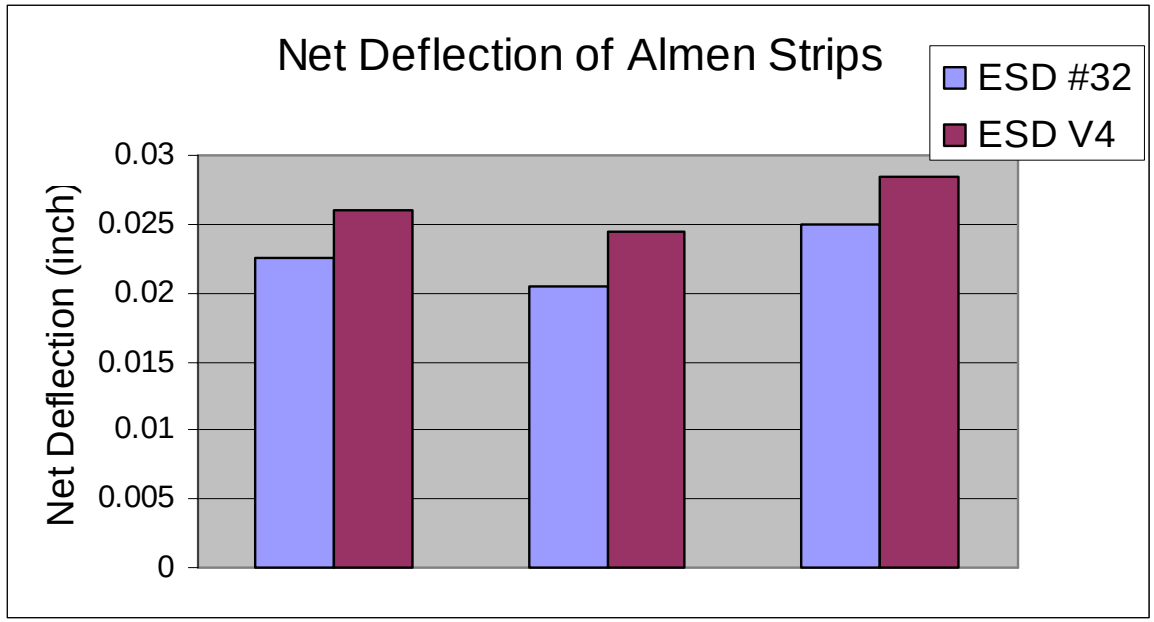
Fatigue


200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Maximum Stress (psi)
10,000
100,000
1,000,000
cycles to failure
Baseline
Baseline with Divot
ESD + UIT

Fatigue Debit (% of Baseline)



Residual Stress



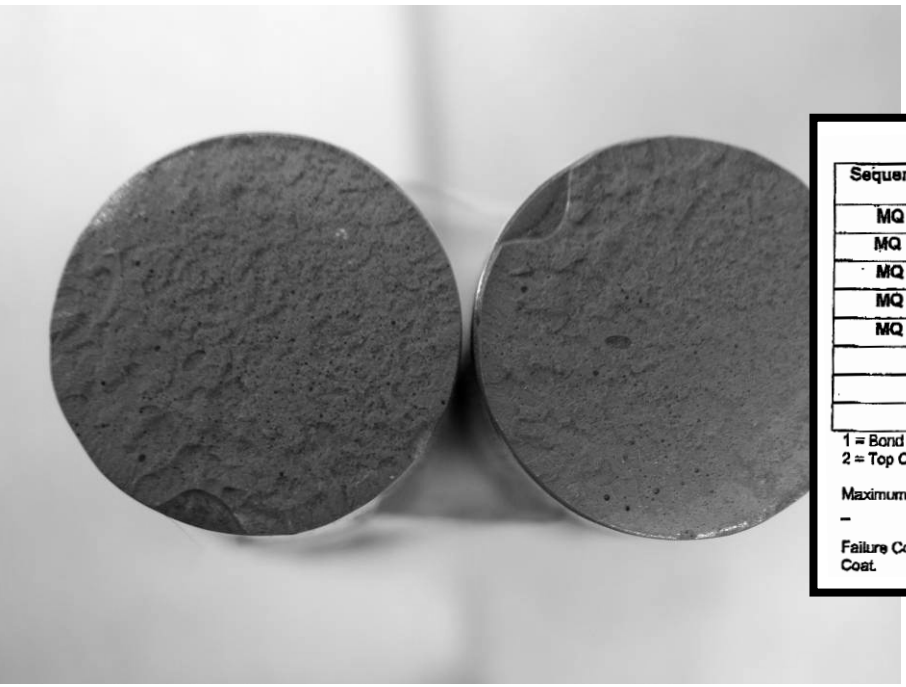
- The objective of including residual stress analysis in the JTP was to obtain an indication of the presence of residual stresses due to the ESD process.
- Results: Tensile stresses with ESD, Higher tensile stresses with increased energy (V4).

Corrosion

Coupon #	Parameters	Surface Finish
11	V4	Yes
12	V4	Yes
13	V4	Yes
14	#32	Yes
15	#32	Yes
16	#32	Yes
17	#32 + UIT	Yes
18	#32 + UIT	Yes
19	#32 + UIT	Yes
20	#32 bead-on-plate	No
21	#32 bead-on-plate	No
22	#32 bead-on-plate	No
23	#32 bead-on-plate	No
24	#32 bead-on-plate	No
25	#32 bead-on-plate	No

ASTM B117 performed

Adhesion Bond



MECHANICAL PROPERTIES

Sequence	Specimen Number	Actual Diameter	Actual Area	Thickness 1	Thickness 2	Tensile Strength Load lbs.	Tensile Strength Lb/sq"	Failure
MQ	#1	1.00	.785			7453	9494	C
MQ	#2	1.00	.785			8061	10268	C
MQ	#3	1.00	.785			8822	11238	C
MQ	#4	1.00	.785			7017	8938	C
MQ	#5	1.00	.785			8490	10815	C

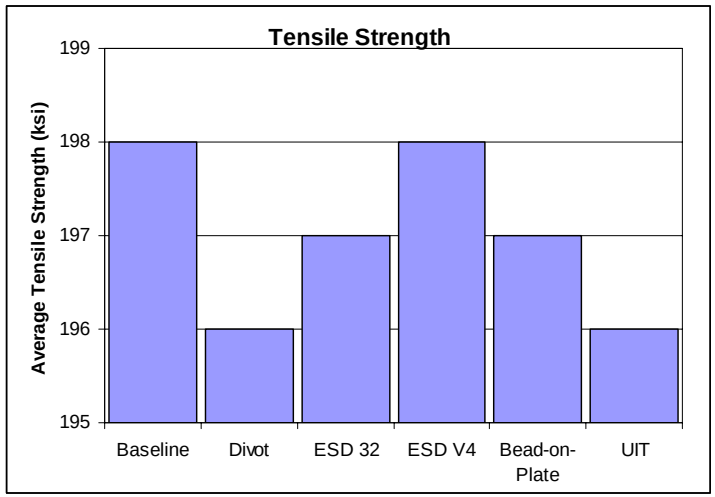
1 = Bond Coat, if required
2 = Top Coating

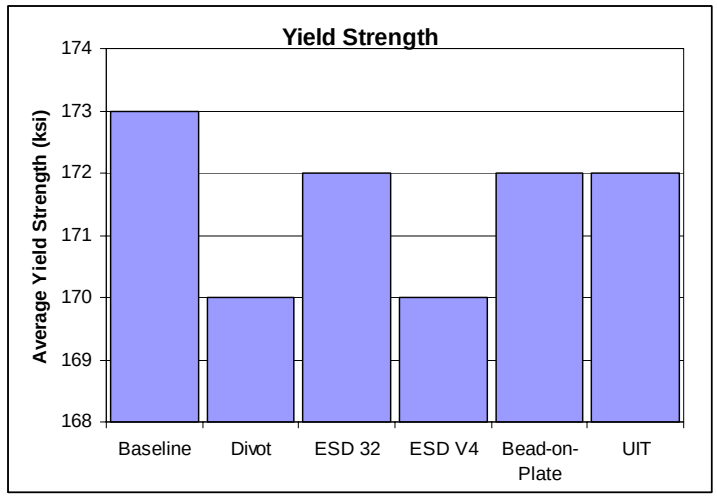
Maximum Strength: 11235 Minimum Strength: 7017 Average Strength: 8350

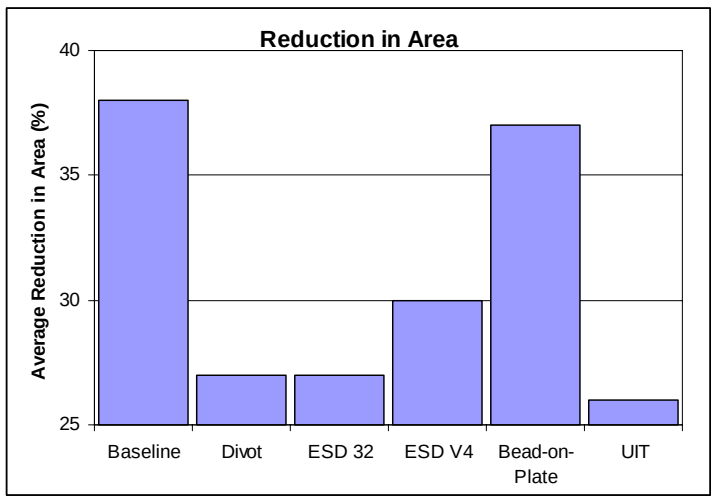
Failure Codes: Failure located within the (A) Coating, (B) Coating-Substrate Surface, (C) Adhesive Bond, (D) Bond Coating and Surface Coat.

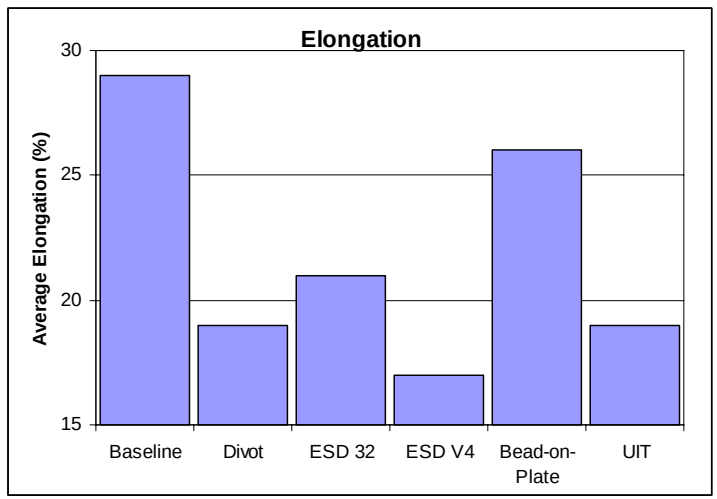
ASTM C 633 performed

Tensile

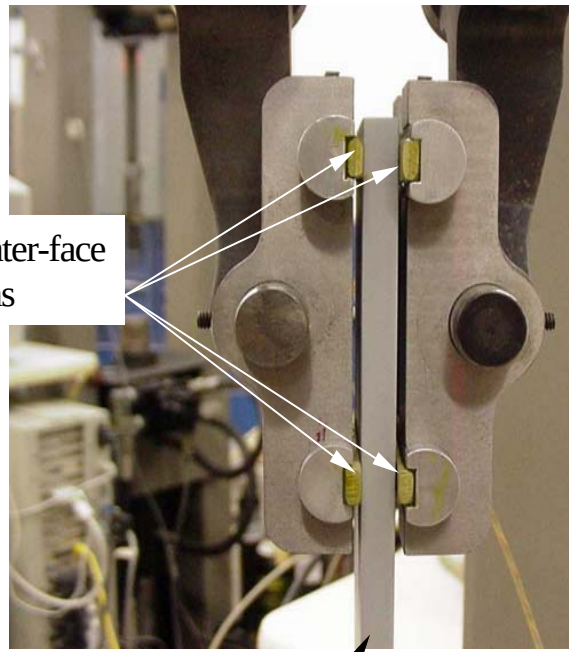

Tensile Strength
Average Tensile Strength (ksi)
199
198
197
196
195
Baseline
Divot
ESD 32
ESD V4
Bead-on-Plate
UIT


Yield Strength
Average Yield Strength (ksi)
174
173
172
171
170
169
168
Baseline
Divot
ESD 32
ESD V4
Bead-on-Plate
UIT


Reduction in Area
Average Reduction in Area (%)
40
35
30
25
Baseline
Divot
ESD 32
ESD V4
Bead-on-Plate
UIT

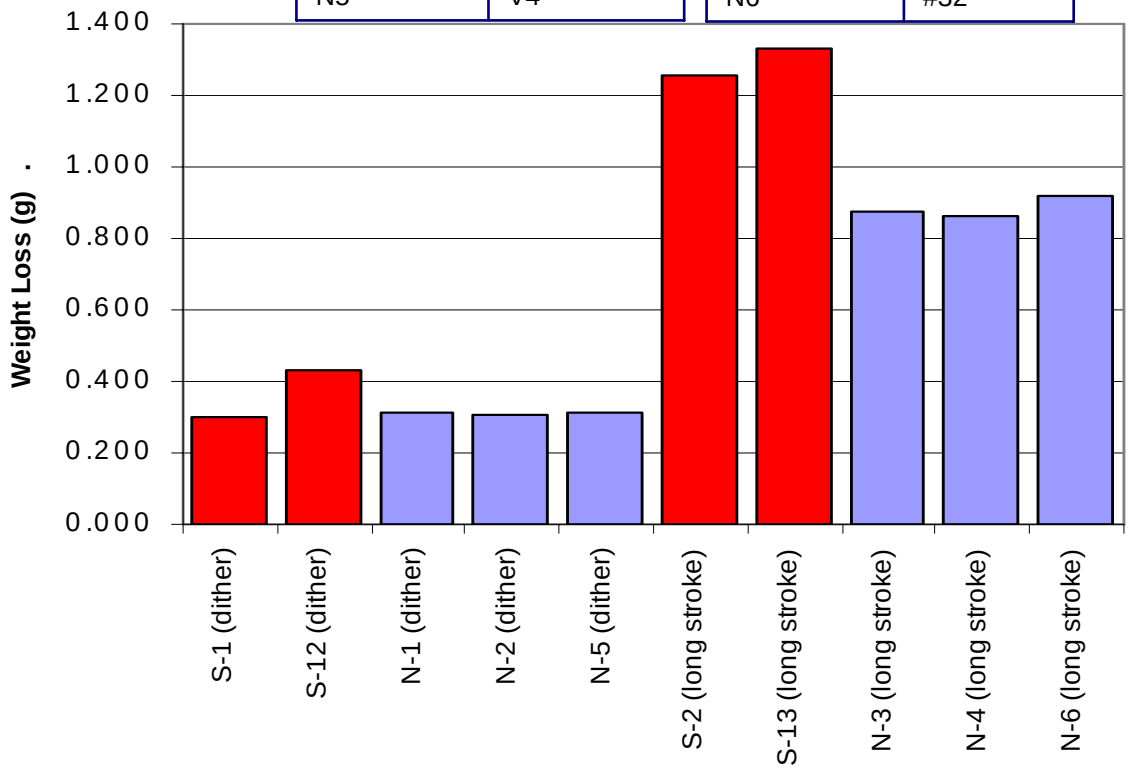

Elongation
Average Elongation (%)
30
25
20
15
Baseline
Divot
ESD 32
ESD V4
Bead-on-Plate
UIT

Hamilton Sundstrand Wear



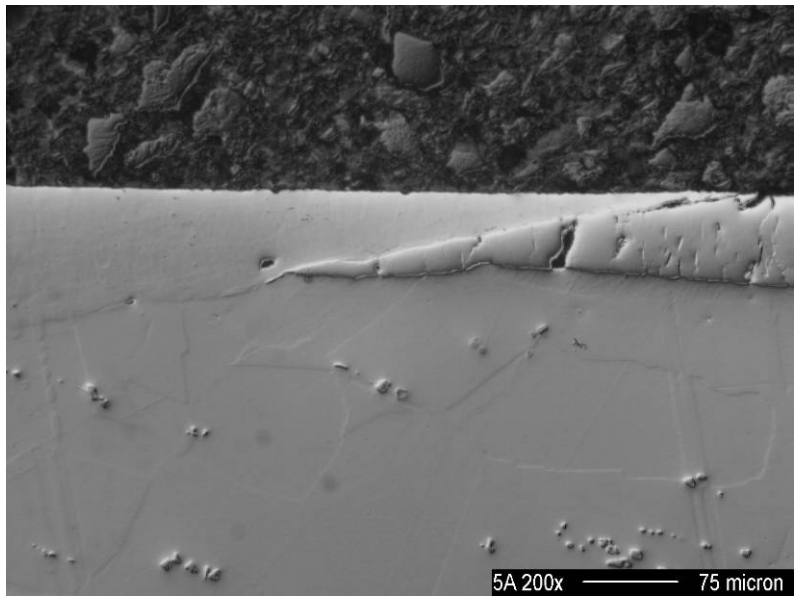
Short stroke (fretting)	
S1 and S12	Baseline
N1	#32 + UIT
N2	#32
N5	V4

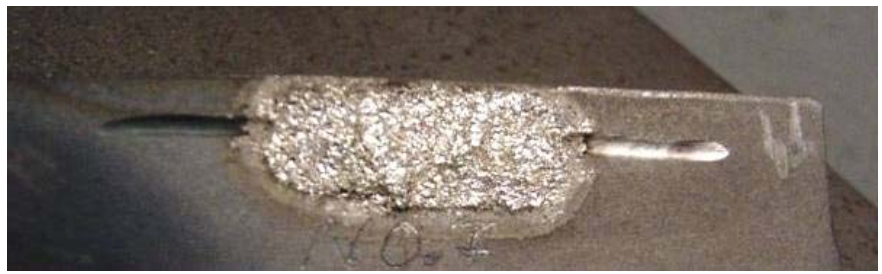
Long stroke (sliding)	
S2 and S13	Baseline
N3	V4
N4	#32 + UIT
N6	#32

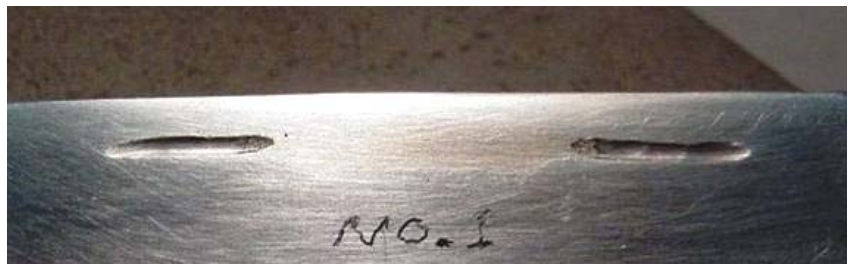


Chrome Repair

Into the substrate

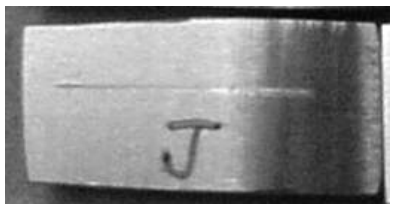


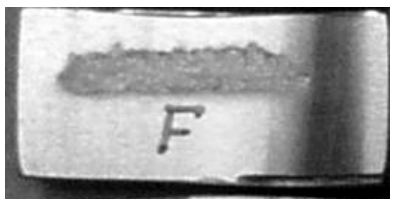




Chrome Repair

In the chrome only - scratches



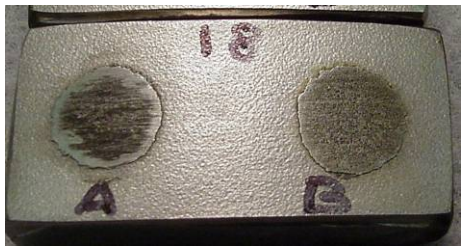


Strip and Rechrome

ESD fill →

Resurface

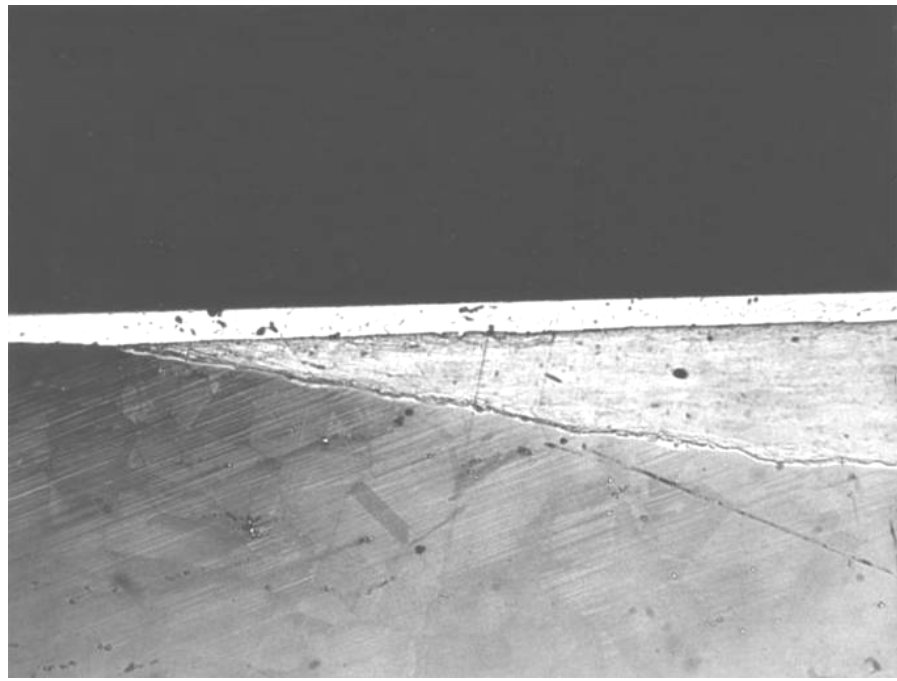
Strip →



Resurface →

Rechrome

FPI →

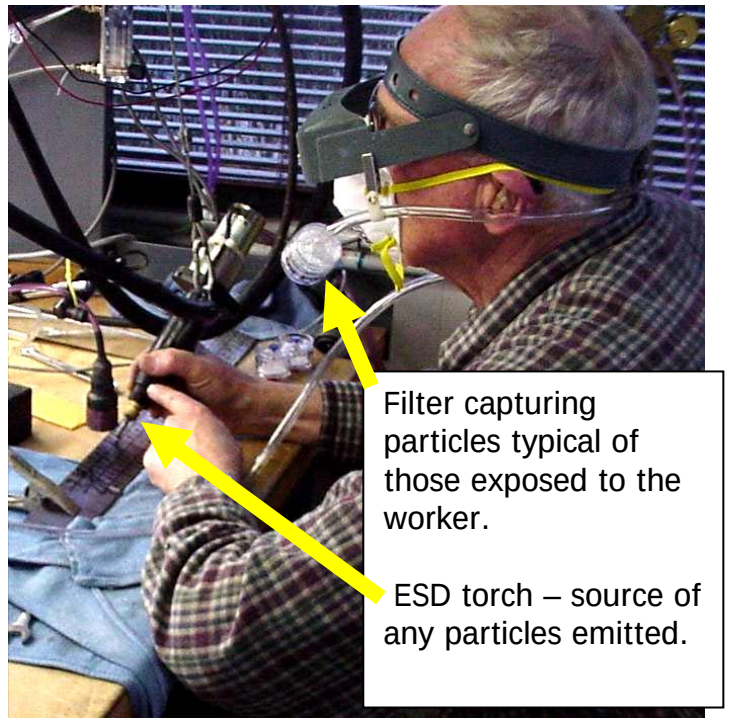


Chrome Particle Emissions

The ESD repair of chromium (EHC) does produce fine particulate of metallic chromium and hexavalent chromium.

At 6” and 12”, up to 5 micrograms were measured.

No hexavalent chromium was found at the face level, even after collection of 1 cubic meter of air (8+ hours of exposure).



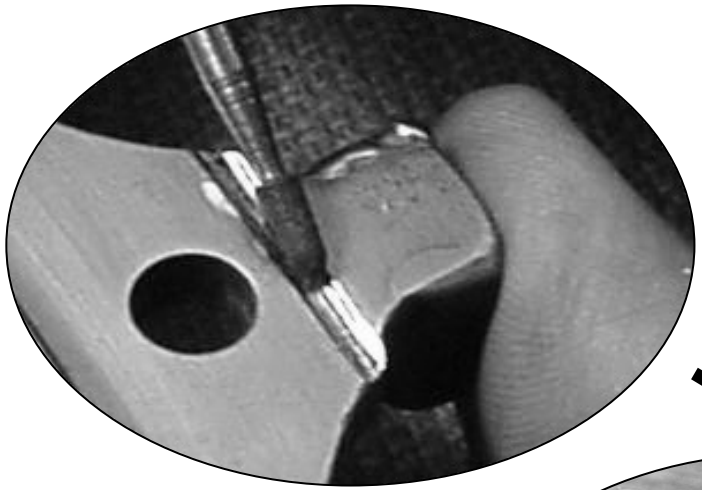
From Material Properties To Components

#5 Bearing Housing (410 SS)
Stator Segment (IN 718)
Compressor Rear Shaft (Chrome Plate)

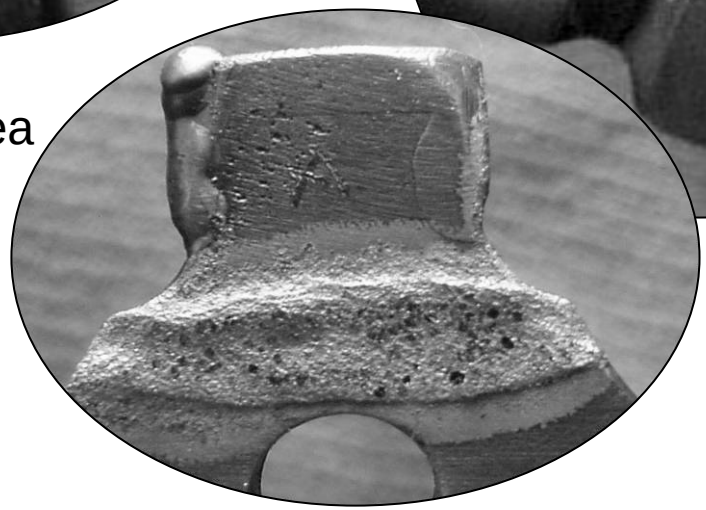
#5 Bearing Housing

P/N 712141
TF 33
AMS 5613
(410 stainless steel)

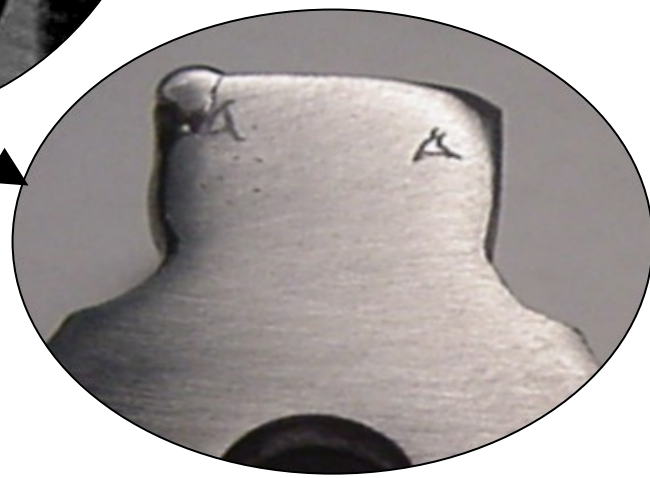
#5 Bearing Housing



Excavate
the defective area

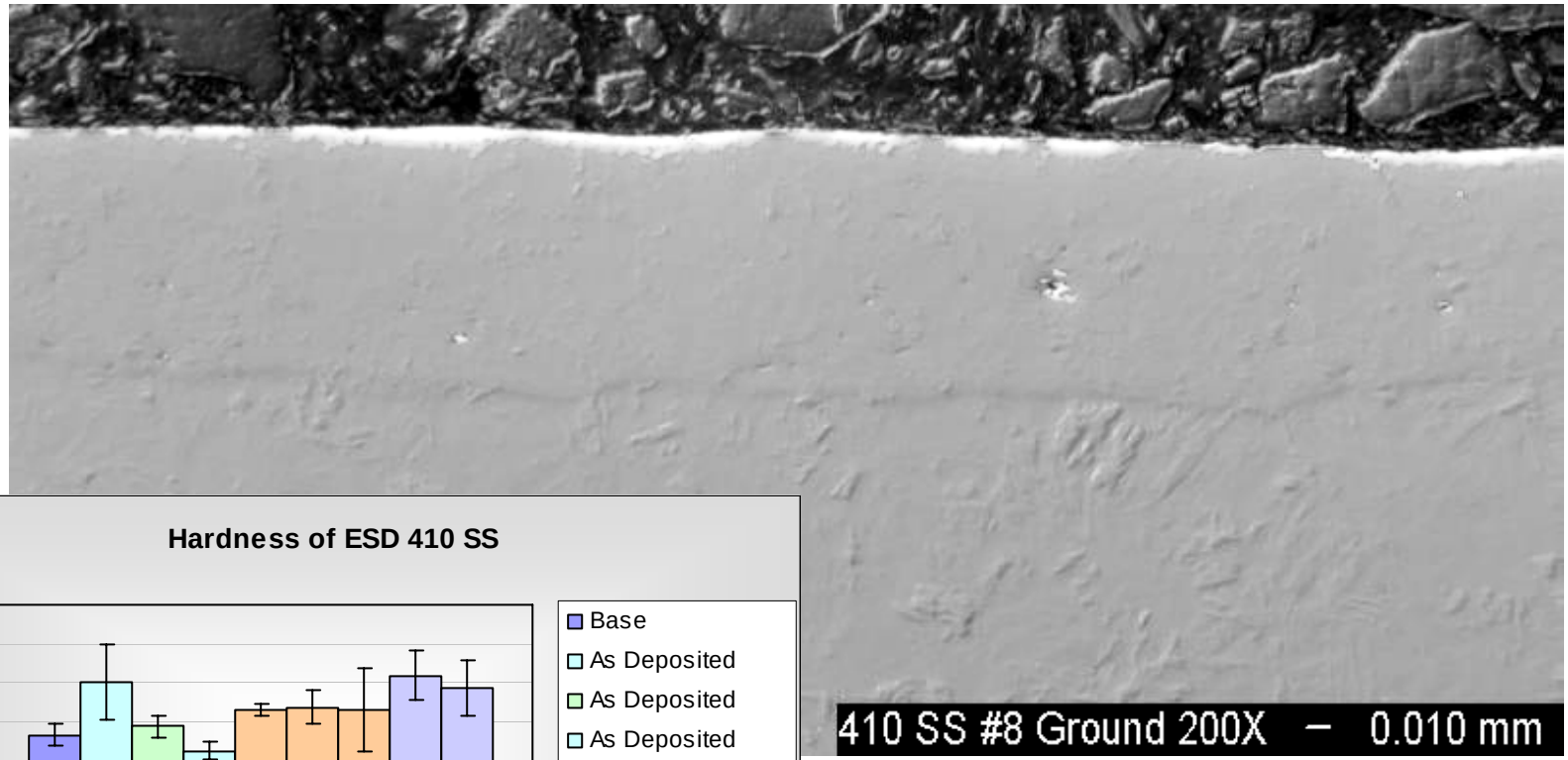


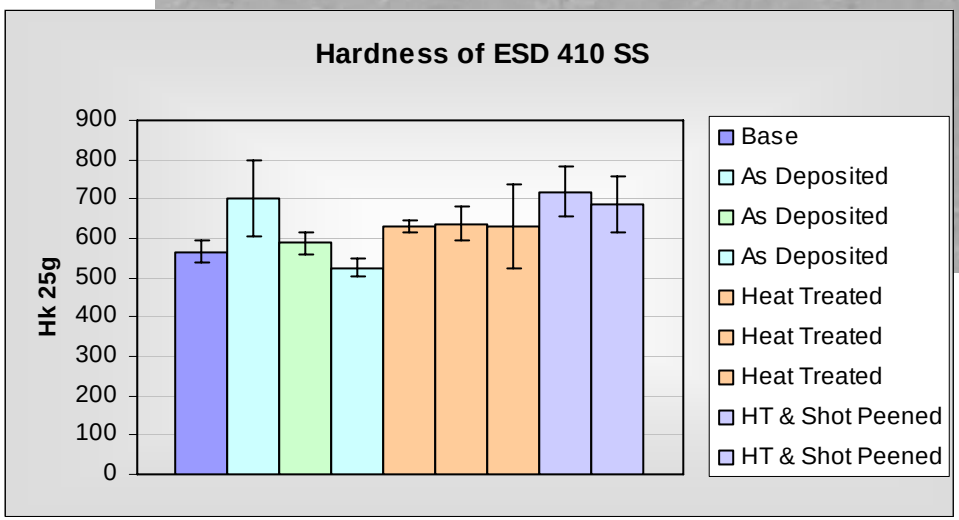
Fill with ESD



Blend to original surface

#5 Bearing Housing



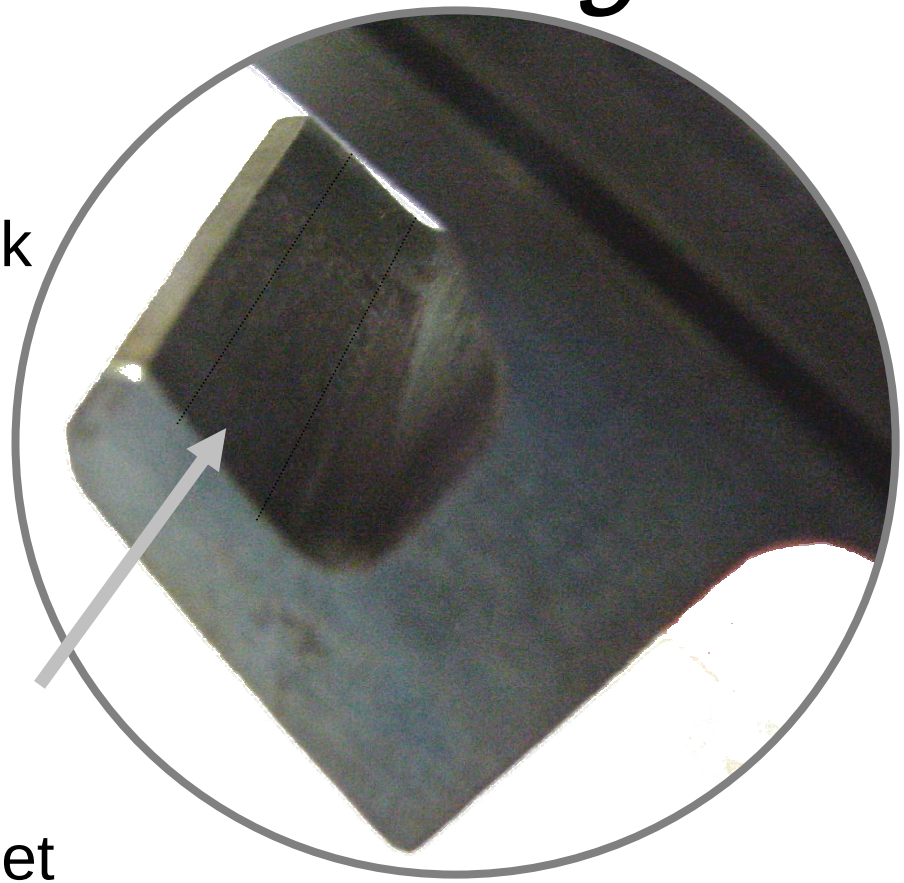


Welding Procedure Specification and hands on demonstration delivered at PEWG, Las Vegas, April 2004.

Stator Segment 10-12 Stage

P/N 4077880
F100 – 229
Inconel 718

Stator Segment 10-12 Stage



>0.005” deep wear in hook
non-line-of-sight

Current repair:
Cut off hook,
weld on new,
heat treat part

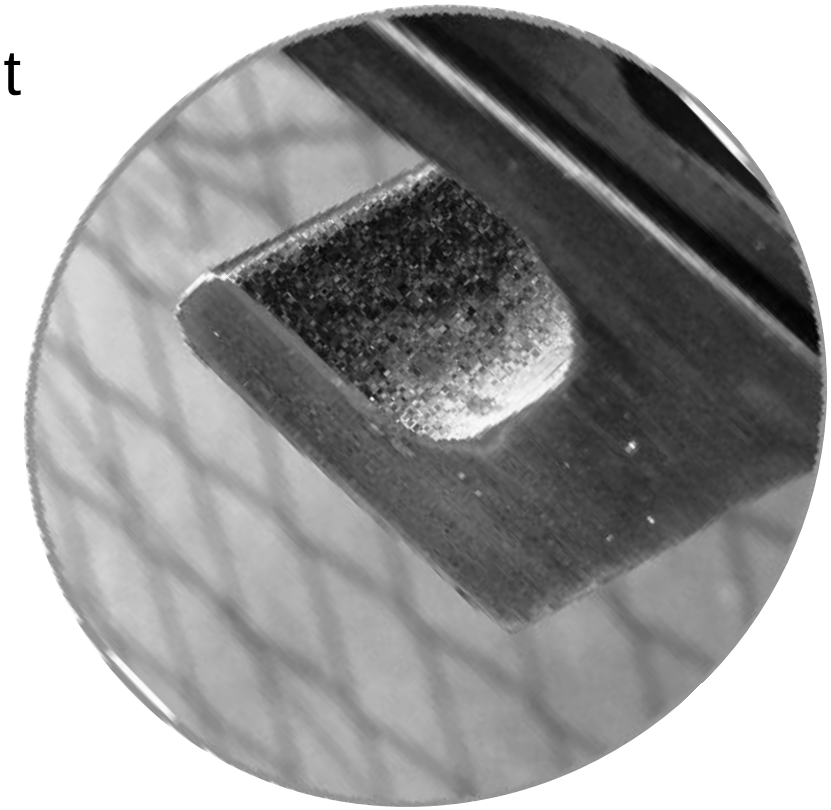
no repair if the part has met permissible heat treat cycles

Stator Segment 10-12 Stage

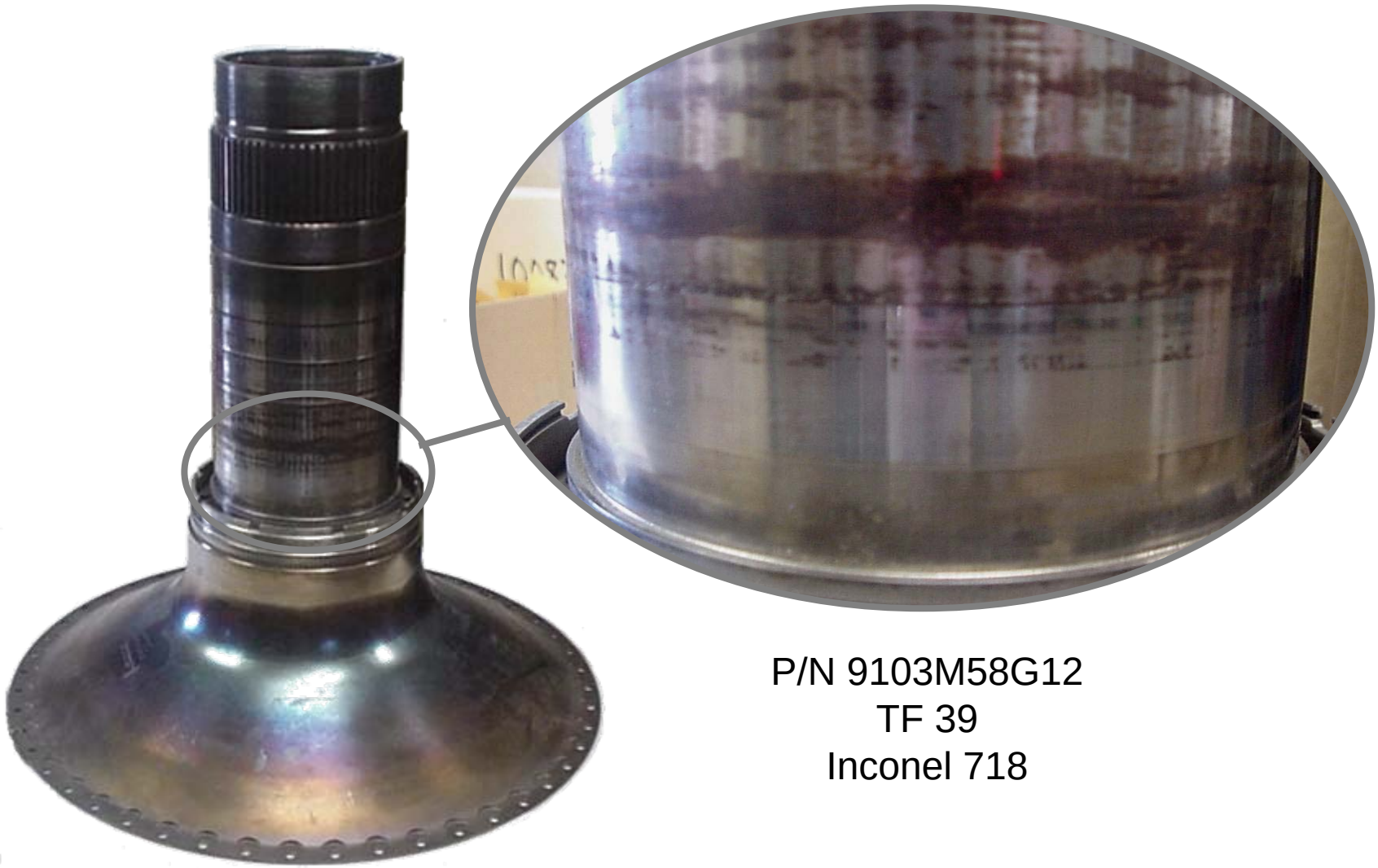
Hardness same as parent material

Wear resistant to “chattering”

ESD repair technique complete



Compressor Rear Shaft

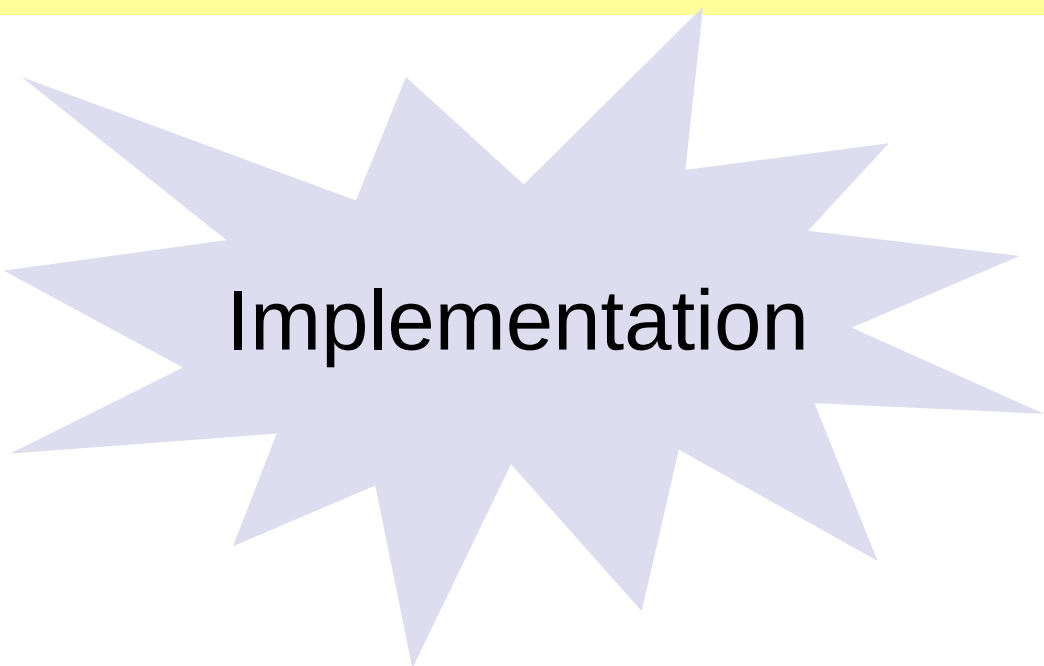


P/N 9103M58G12
TF 39
Inconel 718

In Summary

- *Joint Test Report*

HCAT Member WorkSpace →ESD→Test Plans→Demonstration Plan



ASAP Advanced Surfaces And Processes, Inc.

Results of materials testing for ElectroSpark Deposition

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